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| Title | Technology-enhanced learning for improving complex problem-solving expertise |
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| Citation | The IEEE 13th International Conference on Advanced Learning Technologies (ICALT 2013), Beijing, China, 15-18 July 2013. In Conference Proceedings, 2013, p. 379-381 |
| Issued Date | 2013 |
| URL | http://hdl.handle.net/10722/185097 |
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Technology-Enhanced Learning for Improving Complex Problem-Solving Expertise

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Abstract—Learning through complex problem solving has received increased attention in educational areas. This is particularly the case in challenging domains such as medical education, where problem-based learning (PBL) is widely adopted and found to be effective in helping students to improve their abilities in clinical reasoning, problem solving, and self-directed and cooperative learning. However, there are concerns about PBL's effects on development of systemic knowledge structures and efficient reasoning processes, which are critical for expertise development. To address the challenge, a technology-enhanced learning environment is proposed in this study, aiming to improve students' complex problem-solving expertise by scaffolding their problem solving or reasoning processes as well as knowledge construction with support of expert knowledge.

Keywords—technology-enhanced learning; complex problem solving; expertise development

I. INTRODUCTION

Problem solving is a common activity people encounter every day, and quite a number of the daily problems are ill-structured or complex problems. This has caused increased attention to improvement of students' complex problem solving abilities in realistic contexts. Particularly in challenging domains such as medical education, most problems are ill-structured by nature. In this context, problem-based learning (PBL) has been increasingly used in medical schools over the last few decades. Using a realistic clinical problem as both the beginning and anchoring of learning with minimal guidance from instructors, PBL aims at helping students to apply knowledge and develop problem-solving skills in the contexts of patient problems. Thus, PBL makes a valuable contribution to deep learning where students develop their abilities in clinical reasoning, problem solving, and self-directed and cooperative learning [1].

However, the results of studies on comparing traditional and PBL curricula are inconclusive and inconsistent, indicating a lack of convincing evidence for the superiority of PBL over the traditional curriculum [2]. PBL is found to have limitations in helping students to develop systemic knowledge structures and efficient reasoning processes, and in providing students with

adequate professional support to guide their complex problem-solving processes.

As noted in [3] and [4], although PBL has advantages of promoting active and reflective knowledge-building for actions, careful research is needed to understand whether and how these potentials might be realized. However, studies on design and development effective instructional methods and learning environments to improve students' complex problem solving expertise have been limited. To address the challenge, this study is to investigate how a technology-enhanced learning environment can be designed to improve complex problem-solving expertise.

II. THEORETICAL FOUNDATION

Research about expert-novice differences found that better problem-solving performance is associated with extensive and coherent knowledge structures and superior problem-solving or reasoning strategies, and that superior reasoning strategies substantially count on refined knowledge structures [5]. Development of problem-solving or reasoning processes or systemic knowledge structures needs extensive learning and practice, more preferably under the guidance of domain experts [6]. Therefore, development of expertise in complex problem solving should consider helping students to improve their performance in both aspects with support of expert knowledge.

Further, learning theories of complex problem solving including situated learning [7] and cognitive apprenticeship strategies [8] have been widely used in situated learning contexts such as PBL. Based on these theories, a problem-based learning environment should involve an authentic learning context, externalizing complex cognitive processes, and providing expert guidance on learning processes. Among them, mental models to externalize complex cognitive processes have received increased attention [9].

Mental models can be linked to the use of model-centered instruction to uncover the cognitive processes and architectures held by experts to gain insight into the nature of complex problem solving [10]. As noted by [11], an effective problem-solving instruction needs to be able to reveal the implicit mental models that are

associated with chains of actions and the underlying knowledge structures. Model-centered instruction (MCI) can support student learning by constructing mental models for ill-structures problem solving [12], as well as support the externalization of expert mental models by identifying and describing their problem-solving practice, providing students with the key information to move toward expertise [13].

III. DESIGN OF THE LEARNING ENVIRONMENT

Based on the above theoretic investigation, a technology-enhanced learning environment for complex problem-solving is proposed in this study, aiming to improve students' complex problem-solving expertise by scaffolding their problem solving or reasoning processes as well as knowledge construction with support of expert knowledge. Glaucoma diagnosis is chosen as the learning topic in this study as it belongs to complex and ill-structured problem domain, and it is a common learning content for medical students.

A. Instructional Interventions

There are two learning modes provided in the designed learning environment: self-explorative learning and expert-supported learning. The difference between them is that expert guidance is only provided in expert-supported learning mode while not in self-explorative learning mode. Same learning cases collected and adapted by domain experts and educational practitioners are used in both learning modes. The learning process may start from selection of a learning case from the case database, followed by which students can view initial information of the case including patient background and chief complaint. The detailed learning processes in both modes are described in the following.

B. Self-Explorative Learning

After selecting a case, the student can conduct a series of medical examinations of the patient for further diagnosis. Relevant examination results are shown to students in forms of laboratory data, images, and brief descriptions under each examination item (see Fig. 1).

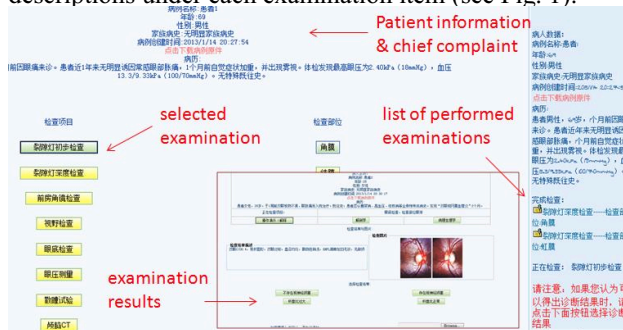


Figure 1. Exploration with problems.

Based on the information, students may conduct a number of examinations and diagnostic judgment until they make a conclusive decision. In this way, students

learn to solve a clinical case by carrying out a series of exploration and reasoning actions in an independent way. After going through a number of cases, students are required to reflect on these cases and build up a mental model or knowledge map to externalize the knowledge underlying their reasoning processes.

C. Expert-Supported Learning

Fig. 2 shows the expert-supported learning environment in this study. Students may select clinical cases and solve them through a number of activities, similar to the self-explorative learning mode, but additionally provided with expert knowledge to guide their problem-solving processes. After completing a case, the student's problem-solving process with the case can be captured by the system and presented as a diagnostic diagram for his/her review. The diagnostic diagram includes initial information of the case, performed medical examinations in a sequence, and diagnostic judgment after each examination.

Distinct differences between the student and the expert in their problem-solving processes can be captured by the system in the diagnostic diagram and demonstrated to students when needed. In this way, students can identify the expert reasoning process for each case and consider how to improve their own problem-solving processes. In addition, after going through a numbers of cases, students are required to reflect on their problem-solving processes and build up a mental model or knowledge map to externalize the knowledge underlying the cases.

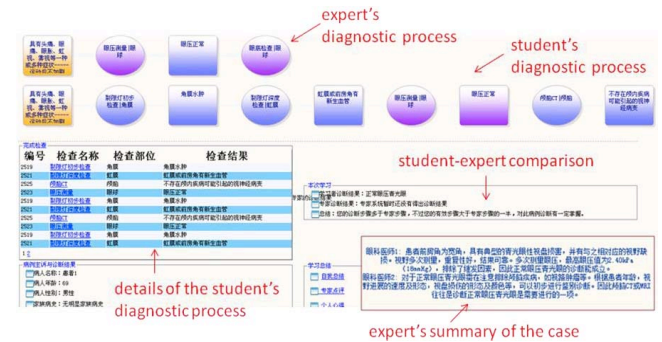


Figure 2. Expert-supported learning.

IV. A CASE STUDY

In the pilot case study, an example of glaucoma diagnostic case was selected to demonstrate the expert-guided learning process for complex problem solving within the designed learning environment. The problem solving and knowledge construction processes in this case are elaborated below.

1) *Problem Initiation.* A case is selected by the student from the case database. Then, relevant background and chief complaint records of the patient is presented in a pop-up learning window, which comprises basic information of the patient such as gender, age, family and personal medical history, and anomalies such as "eyesight faintness" or "continues headache for over a month."

2) *Problem Solving*. Based on the initial information, a preliminary diagnostic plan is formed by the student. Following the plan, the student selects certain eye examinations for the patient and receives relevant results. After several steps, the student is able to draw a conclusion based on relevant information from a series of examinations.

3) *Reflection on Problem Solving with Expert Guidance*. After submitting the diagnostic conclusion, the student can review and reflect on his/her diagnostic process captured by the system in a diagram. The diagnostic diagram includes initial information of the patient, performed examination in a sequence, and clinical judgment after each examination. The student may practice with the same case for several times.

Once the student's diagnostic process reaches some degree of similarity with that of the expert, the diagnostic diagram of the expert for the same case can be viewed by the student, and the differences between the student and expert in their diagnostic processes are captured and indicated by the system for comparison and reflection. Moreover, the expert's summary on the case and the diagnostic process is provided as additional guidance to facilitate students' learning with the case. Meantime, the student can select to post his/her diagnostic diagram to online forums for comments from experts and peers.

4) *Knowledge Construction with Expert Guidance*. After completing a number of cases, the student is required to review and summarize these cases by drawing a knowledge map to represent the domain knowledge of Glaucoma diagnosis. The student can select to post his/her knowledge map to online forums for comments from experts and peers. Further, the expert's knowledge map can be provided to students in due course for reflections and further learning.

V. CONCLUSION

In complex or ill-structured problem solving contexts, there are limited studies on design of instructional models or learning environment for effective learning and instructions with complex problems. Although PBL is proposed as an innovative approach to facilitating problem-solving learning and is widely used in medical schools, it has weaknesses in knowledge construction and reasoning efficiency. To meet the challenge, a technology-enhanced learning environment is proposed on the basis of studies on expertise development and relevant learning theories. It aims to improve students' expertise in complex problem domains by scaffolding their reasoning processes and knowledge construction with the support of expert knowledge.

In the future study, evaluation of the designed learning environment will be carried out with medical students. The two learning modes provided by the system will be compared to examine their effects on complex problem-solving learning. Students' perceptions of the designed learning environment will be analyzed. Further, students' learning achievement from using the proposed learning environment will be assessed regarding reasoning

and knowledge construction performance. The evaluation results will be analyzed to examine whether and how the proposed learning environment can improve students' complex problem-solving expertise.

ACKNOWLEDGMENT

This research is supported by the Seeding Fund for Basic Research (No. 201011159210 & No. 201111159044) from The University of Hong Kong.

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